

# Photographic Techniques in Experimental Hydraulics

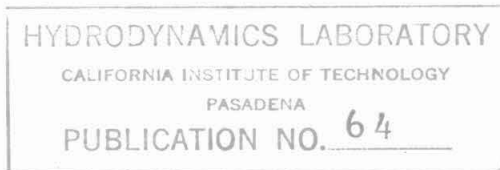
by

HUGH STEVENS BELL

*Research Engineer, Hydrodynamics Laboratory*

CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena, California



Reprinted from

PROCEEDINGS OF THE THIRD HYDRAULICS CONFERENCE

Bulletin 31, University of Iowa Studies in Engineering

1947

## PHOTOGRAPHIC TECHNIQUES IN EXPERIMENTAL HYDRAULICS

HUGH STEVENS BELL

California Institute of Technology, Pasadena, Calif.

The field of fluid mechanics presents one long series of challenges to the ingenuity of the photographer. It is no easy task to photograph transparent things under the most favorable circumstances. Air and water, the two most commonly photographed fluids, are transparent to the point of complete invisibility and the conditions encountered in hydraulic research rarely can be classed as photographically favorable even by the most rugged optimist. All too often experimental apparatus is designed by engineers for the use of other engineers who, sooner or later, realize that photographs might clarify certain difficult passages in a report that has been or must be written. Consequently texts on hydraulics are illustrated profusely with excellent line drawings.

During the past quarter century, progress in photography has been nothing less than spectacular. The rankest amateur can do today what the professional photographer only dreamed of doing 25 years ago. Simplification has gone hand in hand with improvement in lenses, light sources, emulsions, exposure meters, cameras, developers, darkroom equipment and technical literature. Consequently old techniques give better results and have wider application, and new ones become possible. For example, pin-hole photography and the 82-year-old Schlieren method both are being used successfully to obtain motion pictures at rates in excess of 100,000 frames per second, and the rapid improvement of gaseous discharge lamps has made it possible to develop a new technique based upon the extremely short, brilliant flashes of light these lamps can emit at rates of several thousand per second.

Experimental hydraulics probably makes use of a wider variety of photographic techniques than any other science. Wartime restrictions, as yet not removed, prevent the discussion of several

that are of considerable importance. There is space to consider briefly a few that are of particular interest. Some of them are very old, others are modernized versions of techniques that demonstrated their value long ago, and a few may be considered of comparatively recent origin.

#### THE SCHLIEREN METHOD

The Schlieren method [1] adapts to photographic use the knife-edge technique which has long been used in testing the optical perfection of lenses and mirrors. Schlieren photographs are possible because the refractive index of air is sensitive to minute variations in pressure and temperature. A jet of air, a sound wave, the pressure wave at the nose of a speeding projectile and the turbulent wake behind it, or even the heat rising from one's hand can all be recorded by this technique which actually photographs the density gradient. In its many variations the method requires either mirrors or lenses or combinations thereof, and all must be of the highest optical quality. Application is limited by the fact that the area photographed can be no larger than the mirror or lens against which the object is seen. Because of the great cost of optically perfect lenses of large size, mirrors are commonly used except in very small installations.

If images are to be sharply defined, the light source must be very small. Even though the method makes highly efficient use of the available light, only the brightest sources are satisfactory. Carbon arcs, the standard of earlier times, can be replaced by the more convenient tungsten arcs, or by high-pressure mercury vapor lamps. The latter are particularly well suited for the purpose. The light source is about 25 mm long by 2 mm wide and has a brightness of approximately 65,000 lumens. For Schlieren use it is masked by a plate in which a 0.001" x 0.004" aperture is cut. A high-pressure mercury vapor lamp may be burned normally so as to give a visually steady light on either AC or DC while the delicate adjustments demanded by the technique are being made and then, by simply throwing a switch, it may be operated as a high-speed lamp giving a brilliant flash with a duration of about 3 microseconds. An object moving 2,000 fps would travel only 0.072 in. during the flash [2].

Fig. 1 is an example of Schlieren photography. It shows an airfoil suspended in a wind tunnel in which the mean velocity is about 0.9 that of sound. Flow around the foil becomes super-sonic and shock waves, clearly shown in the picture, are produced.

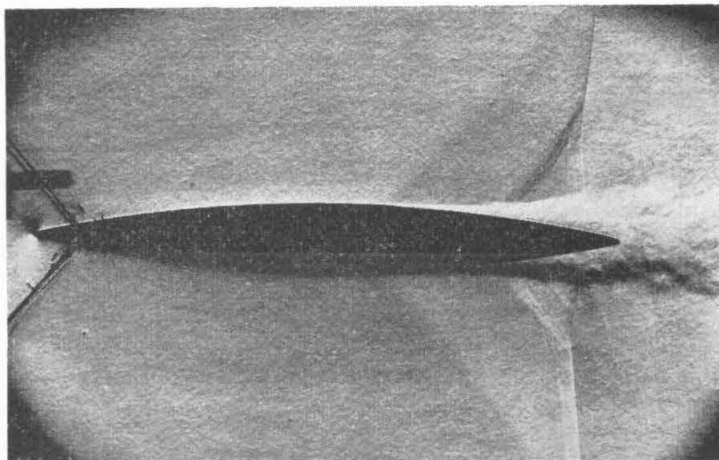


FIG. 1—SCHLIEREN PHOTOGRAPH OF FLOW AROUND AN AIRFOIL IN THE TRAN-  
SONIC TUNNEL AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY, SHOWING  
SEPARATED BOUNDARY LAYER, EXPANSION WAVES, AND SHOCK WAVES.

Exposure: 1 microsecond, spark.

## SHADOWGRAPHS

The shadowgraph technique is as simple as the Schlieren is complicated, requires a minimum of equipment, and can be used to show many of the phenomena photographed by Schlieren. Shadowgraphs lack the delicate detail that can be obtained by the other method, but they are often entirely satisfactory even so.

In its simplest form the shadowgraph technique requires neither camera nor lens, and bromide enlarging paper can be substituted for film. The one indispensable piece of equipment is a "point" light source of high intensity and extremely short duration. The spark gap can be made to meet these specifications rather nicely. By arranging the electrodes so that the spark is greatly foreshortened when viewed from the position of the object, the appar-

ent size is effectively reduced. It is not particularly difficult to obtain durations of a microsecond. With care this can be reduced by a factor of ten [3].

Unless a condenser system is used as a background against which the object is photographed, it is desirable to have the spark gap some 15 feet from the object. The film or paper is placed at a location that must be determined by trial for each set-up, but a distance of about 18 inches is often satisfactory. Contrast increases when the distance is increased, but a point is soon reached beyond which the resolution of the image falls off rapidly. It is necessary to compromise, therefore, on a position affording good contrast and adequate resolution.

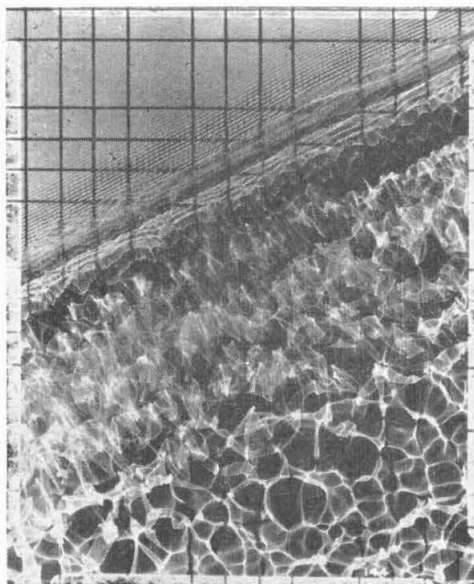


FIG. 2—SHADOWGRAPH, MADE WITHOUT CAMERA OR LENS, OF SHOCKWAVE ENTERING STILL WATER.

Exposure: 100 microseconds, spark.

Fig. 2 is a shadowgraph made without benefit of a camera. It shows, from upper left to lower right, still water, ripples, a shock wave with superimposed ripples, and a highly turbulent area

following the wave. The action took place in a glass-bottomed tank. A sheet of 8" x 10" film was placed parallel to and 5 inches above the water surface. Light from an electric spark traveled horizontally for about 15 feet to a mirror which reflected it vertically so that it passed through a grid of string, the glass bottom of the tank, and then through the water before reaching the film. It would have been almost as effective if the film had been placed below the grid and the light had been reflected vertically downward through the water.

When large areas are to be photographed it is done easily by placing a translucent screen in the plane that would be occupied by the film if no camera were used, and then photographing the screen itself from the rear when the shadows fall upon it. If motion pictures are to be made, the screen is an essential part of the equipment. Thin, white drafting paper makes an inexpensive and entirely acceptable screen, and the tungsten arc, even though it is rated at only 300 watts, is very satisfactory for the light source for motion pictures up to 64 frames per second, on moderately fast film used with an  $f/1.5$  lens.

There are some valid objections to shadowgraphs. They tend to be purely two-dimensional, but it is sometimes possible to overcome this with a grid. The grid in Fig. 2, for example, makes it possible to determine the height of waves by a method developed by Dr. Hans Albert Einstein. If the exposures are made without using a camera the work must be done in a completely darkened room unless slow films or paper are used. Best results are obtained in rooms having ceilings, floors and sidewalls painted black. The possible applications are somewhat limited. Nevertheless the shadowgraph technique is a valuable one, it is extremely simple in operation, and its demands for equipment can be met by the most modest budgets.

#### HIGH-SPEED STILLS

As used here the term "high-speed" indicates exposures of less than 0.0001 second. Such exposures are far beyond the limit of practically all mechanical shutters, and are commonly obtained by the use of electric sparks or gaseous discharge lamps. Because of the comparatively great quantity of light they produce, lamps are

to be preferred to sparks whenever pictures must be made by reflected rather than by transmitted light.

High-speed stills have contributed much to our knowledge of cavitation (Fig. 3), waves, and certain other fluid phenomena, but it is well to remember that pictures which stop motion completely may be less useful than those in which blurring indicates both direction and relative velocity. It is entirely possible to make pictures so technically perfect photographically that they are worthless as sources of data. This fact should be considered carefully before embarking upon a program of high-speed photography.

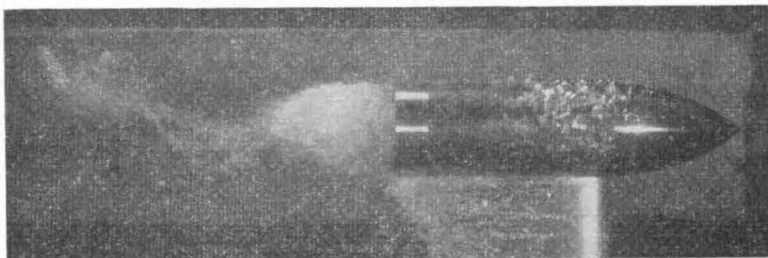


FIG. 3—HIGH-SPEED PHOTOGRAPH OF CAVITATION BUBBLES ON BULLET-SHAPED BODY AND ITS WAKE.

Exposure: 1.5 microseconds, gaseous discharge.

Equipment for making single-flash still pictures is commercially available at prices ranging from less than \$200.00 to somewhat more than \$500.00. The General Electric High-speed Photolight and the General Radio Microflash are in the higher price range, the Strobolux and Kodatron Speedlamp are medium priced, and the Stroblite is less expensive. There is a considerable spread in the duration of the flashes produced by the various types of equipment. The Microflash gives an exposure of 1 to 2 microseconds, the Photolight 2 to 3 microseconds, the Kodatron and Stroblite approximately 35 microseconds, and the Strobolux gives a choice of three spark intensities, the most brilliant of which lasts approximately 100 microseconds. The Strobolux gives less light than the others but has the advantage that it can be used stroboscopically, as its name indicates. This makes it possible to produce multiple-exposure negatives like those showing the complete swing of a golfer, the wind-up of a pitcher, and other similar bits of action.

## MULTIPLE-EXPOSURE STILLS

Multiple-exposure pictures have a definite place in hydraulic research. They have been used with a cleverly devised grid of small air bubbles to show the motion of water in the vicinity of rapidly moving solid bodies. They give valuable information on direction,

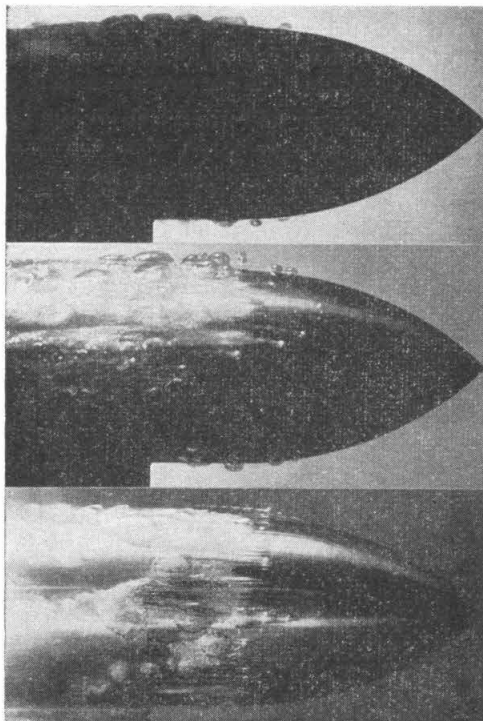


FIG. 4—MULTIPLE-EXPOSURE HIGH-SPEED PHOTOGRAPHS SHOWING IMPORTANCE OF LIGHTING. BRILLIANT INITIAL FLASH WAS FOLLOWED BY SERIES OF SECONDARY FLASHES AT INTERVALS OF  $1/8000$ -SECOND. METHOD SUCCESSFUL ONLY FOR BRIGHT OBJECTS AGAINST DARK BACKGROUNDS. Individual exposures: 1.5 microseconds, gaseous discharges.

velocity and rate of acceleration. For many applications they are better than the conventional streak pictures. It is essential that such negatives show bright objects against dark backgrounds, and to be entirely successful the subject matter must be relatively simple



in order to avoid overlapping which may produce an unintelligible final product.

In the photographs of Fig. 4, taken to show the relative merits of various lighting arrangements, the principal flash is followed by a series of about six minor ones. The images produced by the secondary flashes are lost against a background made brilliant by backlighting (top). A combination of top and back light (center) gives enough emphasis to the secondary images so that they can be traced along the top of the model, but not beneath it. Against dark portions of the model they are conspicuous, in the highlights they are completely lost, just as they are in areas where bubbles are so

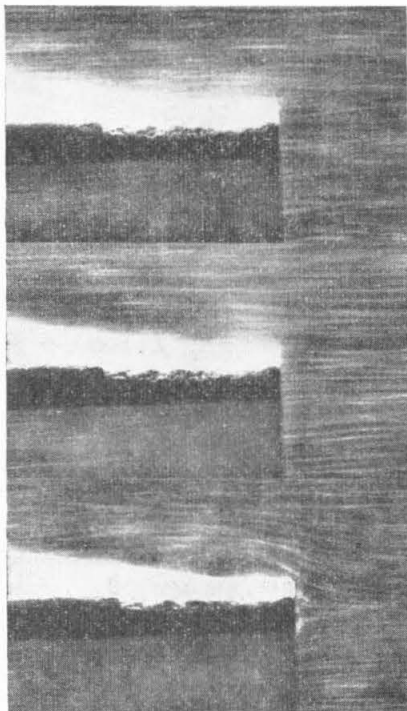


FIG. 5—MULTIPLE-EXPOSURE LOW-SPEED PHOTOGRAPH OF SAMPLING TUBE IN SEDIMENT-LADEN WATER. EACH SAND GRAIN APPEARS AS A SERIES OF BRIGHT DASHES INDICATING THE FLOW PATTERN AS WATER IS WITHDRAWN AT STREAM VELOCITY, 0.7 STREAM VELOCITY, AND AT ZERO VELOCITY.

Total exposure: 1/25 second; individual exposures about 1/150 second, high-pressure mercury-vapor.

numerous that serious overlapping results. With light coming from the front and top, the bubbles stand out conspicuously against the dark background and over the dark areas of the model (bottom). The secondary flashes were at the rate of approximately 8,000 per second, and the pictures they produced gave valuable information on the life history of cavitation bubbles.

A somewhat similar technique was used to obtain the pictures reproduced as Fig. 5. Sand grains are shown in the vicinity of a sampling tube through which water is being withdrawn at the velocity of the stream, at 0.7 stream velocity, and at zero velocity. The exposure was  $1/25$  second but each particle appears as a series of bright dashes because the light source, a high-pressure mercury-vapor lamp, supplied 120 rather long flashes per second.

#### HIGH-SPEED MOTION PICTURES

Stop-and-go motion pictures can not be made at rates in excess of about 150 frames per second. For higher rates special cameras are used in which the film moves continuously and the image usually is moved along at the film speed by some optical device such as a rotating prism or mirror, or a battery of rotating lenses. It is possible, also, to illuminate the object with flashes of light of such short duration that the motion of the film during an exposure is negligible.

As early as 1929 Japanese research workers were photographing sound waves on continuously moving film at 40,000 frames per second [4] and subsequently they were able to increase that rate about 2.5 times. At the N.A.C.A. Aircraft Engine Research Laboratory at Cleveland, Ohio, Mr. Cearcy D. Miller has been photographing what takes place in Diesel and spark-ignition engine cylinders at 40,000 frames per second since 1939. On June 5, 1946, at French Lick, Indiana, Mr. Miller presented a paper before the Society of Automotive Engineers entitled, "The Roles of Detonation Waves and Autoignition in Spark-ignition Engine Knock as Shown by Photographs Taken at 40,000 and 200,000 Frames per Second". These pictures, taken with cameras of his own design, demonstrated that even a rate of 200,000 frames per second is not fast enough to produce really slow-motion pictures of spark-ignition knock. Such a rate would undoubtedly be fast enough to divulge the secrets

of a host of phenomena encountered in other portions of the field of fluid mechanics.

The top speed for commercially available motion picture cameras is about 10,000 frames per second on 8 mm film. Since it requires 62.5 feet of film for 1,000 standard 35 mm frames it is easy to see why the smaller frames must be used in all ultra-speed motion picture photography. If a frame only 1/16 inch in height is used

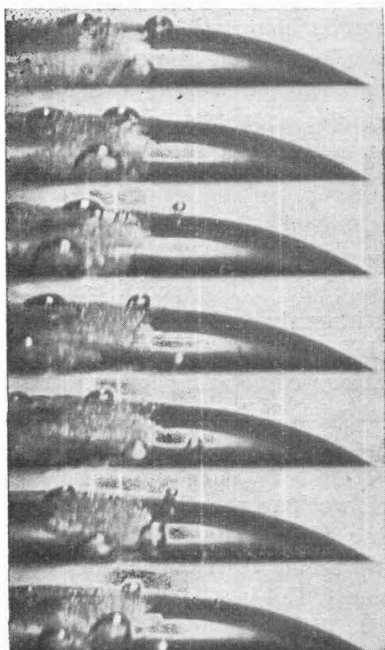


FIG. 6—HIGH-SPEED MOTION PICTURES SHOWING DEVELOPMENT OF SMALL CAVITATION BUBBLE. BUBBLE APPEARS IN SECOND FRAME, RIGHT OF CENTER, AND CAN BE TRACED DIAGONALLY DOWNWARD TOWARD THE LEFT IN SUCCEEDING FRAMES. THE SEVEN PICTURES COVER AN INTERVAL OF 1/500 SECOND.

Frame rate: 3,000 per second;  
exposure: 1.5 microseconds,  
gaseous discharge.

a film speed of 104 feet per second will be sufficient for a rate of 20,000 pictures per second. In the General Radio high-speed camera, which has been on the market for several years, film will reach that speed in the first 40 feet of a 100-foot roll. During an exposure of 2 microseconds the film would move only 1/400-inch, and the blurring of the image would not be objectionable. Present methods of operating gaseous discharge lamps of photographic types do not permit flash rates much beyond 3,500 per second. For the time being, therefore, constant-light sources and cameras incorporating some kind of optical compensator must be used for higher rates. It seems entirely safe to predict that very much higher flash rates soon will be possible with gaseous discharge lamps. This is highly desirable because optical compensators add greatly to the cost of constructing high-speed cameras, and many kinds are difficult to keep in perfect adjustment.

Cameras with a battery of matched lenses mounted upon a

rotating disk have been used successfully in ultra-speed photography on continuously moving film and with a steady light source. It is difficult, however, to prevent lenses from tearing themselves loose from their mountings or even flying apart when they are rotated at very high speeds. During the war years a rotating-lens camera was used with marked success at rates of 60,000 frames per second and upward, to photograph self-luminous subjects such as bursting shells and bombs. The lenses, in this particular instance, were "pin holes" drilled in a metal plate.

Fig. 6 is a strip of 3,000-frame-per-second motion pictures showing the development of cavitation bubbles. Although that rate is not nearly fast enough to provide an acceptable slow-motion picture of the phenomenon, it does permit measurement of the rate of growth of the bubbles. When the frames are studied as a series of stills, they give information that is useful in the interpretation of individual pictures like those in Fig. 7 which show a cavitating hydrofoil. The upper, like the vast majority of photographs, was made by reflected light, and the lower by transmitted light. Each tells the same story in a different manner. Both are valuable.

Motion pictures taken at from 10,000 to 1,000,000 frames per second offer real

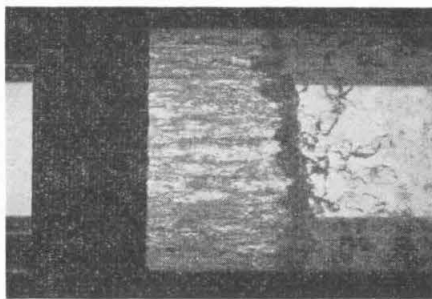
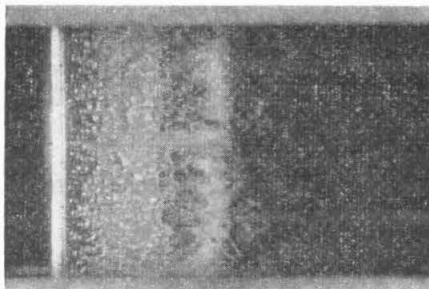


FIG. 7—HIGH-SPEED PHOTOGRAPHS OF CAVITATING HYDROFOIL BY REFLECTED AND BY TRANSMITTED LIGHT. TRANSMITTED LIGHT OFTEN EMPHASIZES DETAILS THAT ARE DIFFICULT TO SHOW BY REFLECTED LIGHT. NOTICE, BELOW, FINEST DETAILS SHOW AGAINST BLACK AREAS WHILE LARGER ELEMENTS SHOW MORE EFFECTIVELY AGAINST LIGHT BACKGROUNDS.

Exposure: 5 microseconds, gaseous discharge.

hope for the complete, or nearly complete, solution of many of the most difficult problems encountered in experimental hydraulics—turbulence, air or sediment entrainment, cavitation, and waves of all kinds, to name but a few. The expenses involved are too great for the vast majority of research laboratories. Cameras, for instance, are custom-built and their cost is measured in thousands of dollars, and equipment for supplying 10,000 or more brilliant flashes per second to high-speed lamps may be even more costly than the camera itself. Film and processing costs are not minor considerations when a 100-foot roll is consumed in less than a second. Then, too, there is the matter of extracting and analyzing the data. An ultra-speed camera can record more data in a fraction of a second than can be analyzed in a hundred man-hours. The cost is great, but so are the rewards.

#### COLOR PHOTOGRAPHY

Within recent years it has been discovered that circularly polarized light makes it possible to see flow patterns and turbulence in dilute suspensions of bentonite or of tobacco mosaic virus [5]. When the action takes place between crossed polaroids it may be seen in color, but if the polaroids are set for maximum light transmission it is seen in black and white. E. A. Hauser and Davis R. Dewey II state that quantitative measurements may be made from photographs of flow patterns in bentonite suspensions [6]. Since the patterns, when they are viewed in color, are predominantly red and blue, they lend themselves nicely to color photography. Actually for phenomena occurring in still water—the wake left by a moving fish (Fig. 8a), the zigzag course of a rising bubble, or the pattern of a jet (Fig. 8b), for example—still pictures in either black and white or in color may be quite satisfactory. When the entire body of fluid is turbulent, however, stills frequently are inadequate and motion pictures in color and at 64 frames per second seem almost mandatory.

Color demands crossed polaroids, and since crossed polaroids hold back all but a small fraction of the light reaching them it becomes rather difficult to obtain an illumination level high enough to make pictures with adequate depth of field at 64 frames per second. Fortunately the area to be illuminated is limited to the size of the polaroids themselves. Three No. 2 reflected photofloods, if mounted

as closely as possible together and burned at about 130 volts, give enough light when they are placed about 5 inches from the polarizer so that Kodachrome film can be used at  $f/4.5$  and 64 frames per

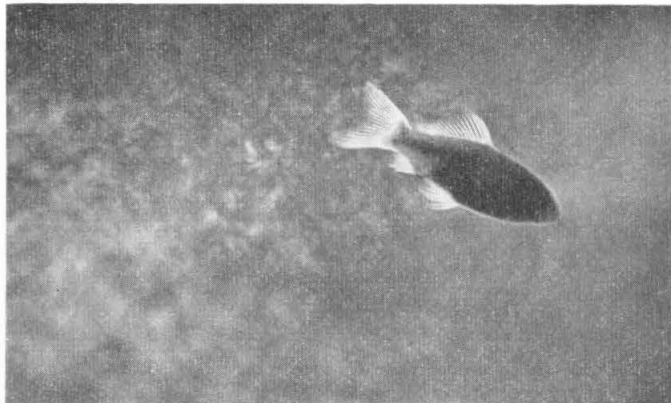


FIG. 8—TURBULENCE AND FLOW PATTERNS IN DILUTE SUSPENSIONS OF BENTONITE OR OF TOBACCO MOSAIC VIRUS ARE MADE VISIBLE BY POLARIZED LIGHT.

(a) WAKE LEFT BY GOLDFISH IN TOBACCO VIRUS. (b) A SUBMERGED JET ADVANCES INTO STILL SUSPENSION OF BENTONITE.

Exposure: 1/200 second, photoflood.

second. Color rendition, though not perfect, is acceptable even though the temperature of the light has been increased considerably by stepping up the voltage. A thin sheet of white drafting paper, placed between the polarizer and the light source, diffuses the light and gives the polarizing screen a little protection from the intense heat. Additional cooling should be provided by directing a strong current of air across the polarizing screen.



FIG. 9—FLOATING CONFETTI SHOWS FLOW PATTERN AND RELATIVE VELOCITIES  
NEAR SPILLWAY CREST.

Exposure: 1 second with crossed pola-screens, brilliant sunlight.

At the Cooperative Laboratory of the Soil Conservation Service at California Institute of Technology color photography has been found to be very useful when experimental work has been done with strongly dyed solutions. In studying the mixing that takes place between density currents, much qualitative information was obtained by running red currents through a reservoir filled with blue water. Mixing produced areas of purple and the action causing the mixing could be observed with equal ease on both sides of the interface. The experiments were recorded in 16-mm Kodachrome

motion pictures. The chief difficulty was in obtaining enough light. The recently developed spotlight type of photoflood should do much to eliminate this difficulty. This is encouraging since the dye technique offers many possibilities for obtaining both qualitative and even somewhat more exact data at moderate cost.

#### NORMAL-SPEED PHOTOGRAPHY

Many of the most valuable techniques depend upon exposures that are long enough to show movement, rather than short enough to eliminate it. Streak patterns made by brilliantly lighted particles probably have furnished more valuable data on fluid flow than anything else that has been recorded photographically. They have been used to show everything from microturbulence [7] to the velocity of approach near a spillway crest, as in Fig. 9. If entrained air bubbles are present they may be all that is required to provide data on flow patterns and local velocities. Fig. 10 gives an ex-

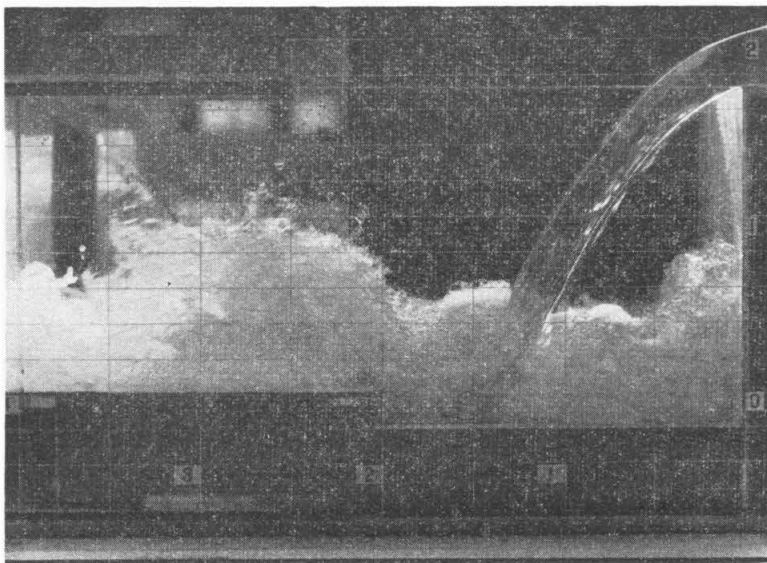


FIG. 10—ENTRAINED AIR BUBBLES SHOW FLOW PATTERNS AND RELATIVE VELOCITIES IN MODEL DROP-STRUCTURE.

Exposure: 1/75 second, daylight accented by photofloods.



cellent record of flow patterns and relative velocities whether or not one knows the exposure or the grid dimensions. It is important to remember that shutter ratings are often unreliable and that actual exposure times may fluctuate widely for any particular setting on many instruments. If measurements are to be made it is

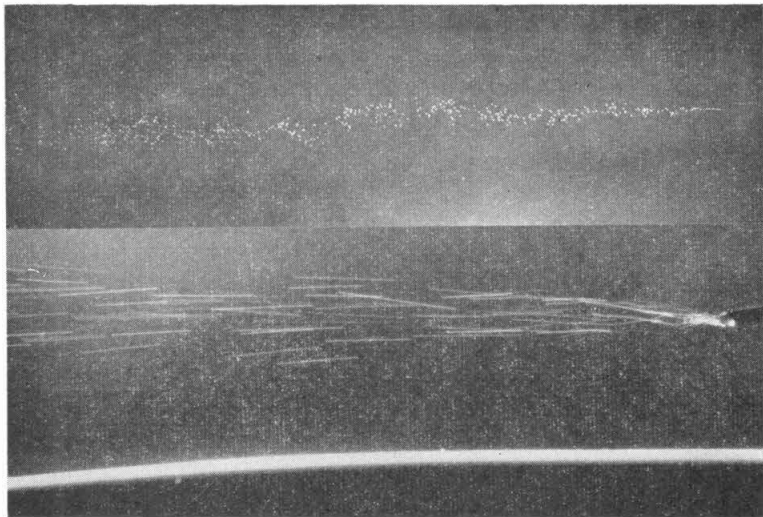


FIG. 11—GLOBULES OF CARBONTETRACHLORIDE-BENZENE MIXTURE ARE USEFUL IN SUB-SURFACE INVESTIGATIONS. ABOVE: DIFFUSION OF A JET BY TURBULENCE.

Exposure: 1/250 second, projection lamp.

BELOW: FLOW LINES NEAR A SUBMERGED BODY.

Exposure: four 1/10 second exposures, tungsten arc.

highly desirable to incorporate in each picture some device, such as a rotating disk on which a white dot or line appears on a black background, moving at a known velocity, so that the actual time of the exposure can be calculated from the angle of rotation. Unless this is done it is unwise to take streak measurements too seriously.

There are many conditions when air bubbles are not present, or not acceptable for purposes of measurement if they are. Aluminum or magnesium flakes, or even confetti, are excellent for use on the surface of a flow, and immiscible globules having a density of unity are quite satisfactory for subsurface use provided the scale

of the phenomenon being investigated is not of minute proportions. Globules of nitrobenzene and olive oil have been highly recommended because light emerges from them  $90^\circ$  from the point of entrance [8]. A mixture of carbontetrachloride and benzene has the advantage of being highly volatile and therefore not messy. It gives satisfactory results when the light is behind the apparatus or low enough to permit the use of a dark background, as in Fig. 11. The dots were photographed in  $1/250$ -second. The streak picture represents four  $1/10$ -second exposures on a single negative. A black background makes it possible to project the negatives life-size directly upon a scale from which readings may be made without benefit of other measuring devices. In photographing globules a small, brilliant light-source is desirable because it is the image of the source which is recorded as a highlight on the globule. A 500-watt projection lamp was used for the upper picture, and a tungsten arc for the lower.

#### GRIDS AND OTHER AIDS

Grids of string are used quite generally without too much satisfaction. They break easily, sag when humidity rises, and need considerable maintenance. A grid of aluminum wire overcomes

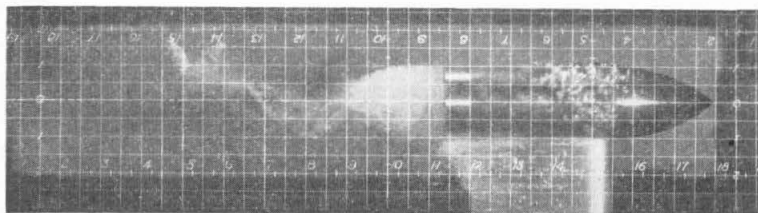


FIG. 12—A SUPERIMPOSED GRID FACILITATES THE TAKING OF DATA FROM PHOTOGRAPHS. THIS ONE WAS PHOTOGRAPHED ON THE CENTERLINE BEFORE THE MODEL WAS INSTALLED AND, THEREFORE, DATA MAY BE READ FROM ITS SCALES WITHOUT USUAL CORRECTION FOR OPTICAL DISTORTION.

these objections effectively but may reflect light so well that the images become objectionably wide due to halation. Swabbing the wire with a solution of sodium hydroxide kills the glare and provides a permanently satisfactory surface.

Parallax always must be reckoned with when exterior grids are

used, and it is ordinarily impossible to use grids within the flow itself. Sometimes this difficulty can be overcome by a very simple technique. In the case of flow in a transparent pipe, for example, it may be possible to photograph a black on white grid at the center when the pipe is full of still water. If the camera position is fixed it then becomes possible to combine a positive transparency of the grid with all subsequent negatives taken at that station and print the pair by projection. The effect is that of having a grid at the center of the pipe during the flow, and measurements at the center-line may be read directly with corrections already made for parallax and all optical distortions due to the pipe itself. The technique is illustrated in Fig. 12. The method has much to recommend it, especially when a long series of pictures is to be made from one location.

Showing topography with string contours may be done so easily

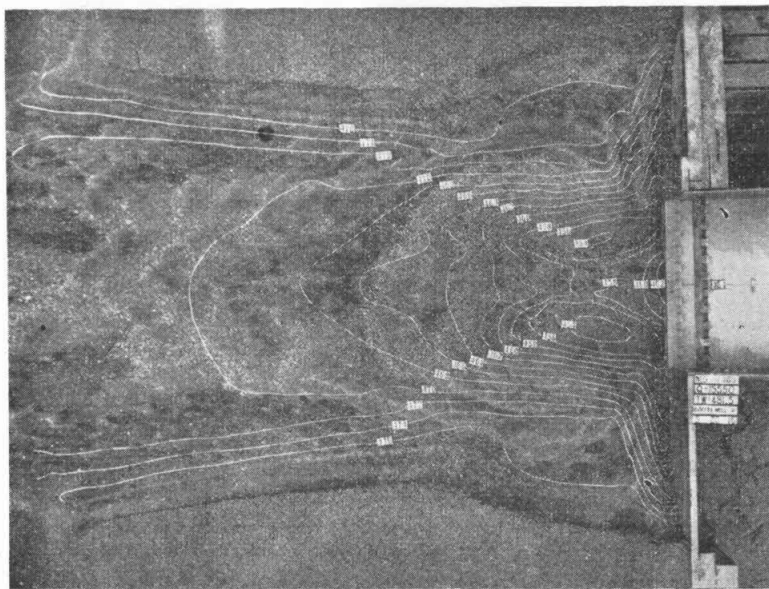


FIG. 13—STRING CONTOURS SHOW RELIEF OF STREAMBED BELOW MODEL SPILLWAY. NOTICE THAT ELEVATIONS ARE GIVEN, AND THAT PERTINENT EXPERIMENTAL DATA RECORDED AT THE RIGHT MAKE REFERENCE TO NOTES ORDINARILY UNNECESSARY.

that one wonders why so little use is made of this device in America. Scour holes, for example, are difficult to photograph under ideal lighting conditions, and are nearly impossible under others. String contours make it easy under any conditions. The various contours are determined by holding the water level at the desired elevations and putting the string along the water lines. A picture like Fig. 13 requires surprisingly little time to set up, including the elevation figures, and it tells a complete story well, not just part of it poorly.

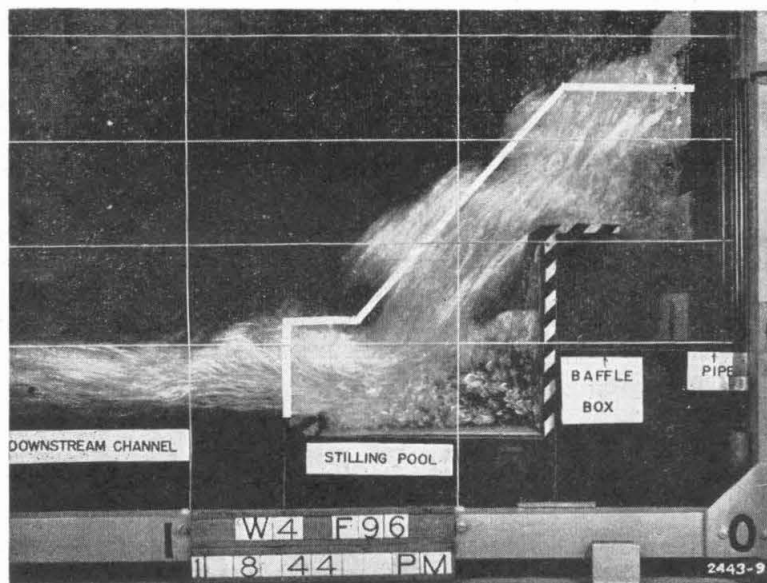


FIG. 14—A GRID, AIR BUBBLES, A MANOMETER TUBE, ADHESIVE TAPE OUTLINES, SIGNS AND EXPERIMENTAL DATA COMBINE TO MAKE THIS PHOTOGRAPH VALUABLE AS DATA AND AS AN ILLUSTRATION.

Exposure: 1/50 second, high-pressure mercury-vapor.

Fig. 14 shows a small model of an energy-dissipation structure. The side of the structure is outlined with white tape stuck to the glass, the front and top of the baffle box are also indicated with bits of tape, stripes 0.1-foot wide are painted across the back of the structure, there is an external wire grid, at the right a mano-

meter shows the back-pressure, pertinent data on the experiment are included above the date. A lot of guess work has been eliminated, and the effort expended was not great.

Not much has been said in this paper about making measurements by photography. The truth is that, though many types of measurements can be made by using photographic techniques, the same information often can be obtained more easily and less expensively by other means. If a camera is the best or the only tool for the job, proper precautions must be taken because just any photographically good picture is probably not going to be good enough if data are to be taken from it.

#### REFERENCES

1. Barnes, N. F. and Bellinger, S. L., "Analyzing Airflow", *General Electric Review*, December 1944.
2. Bellinger, S. L., "High-speed Photolight", *General Electric Review*, March 1944.
3. Edgerton, Harold E., "High-speed Photography", *Handbook of Photography*, ed. by Keith Henney and Beverly Dudley, Whittlesey House, 1939, p. 763.
4. Suhara, T., "New Ultra-speed Kinematographic Camera", Aeronautical Research Institute; Tokyo Imp. Univ. Rept. 60, pp. 187-194. 1930.
5. Stanley, W. M., "Chemical Properties of Viruses", *Scientific Monthly*, Vol. 53, pp. 197-210, Sept. 1941.
6. Hauser, E. A. and Dewey, Davis R., II, "Visual Studies of Flow Patterns", *Journal of Physical Chemistry*, Vol. 46, No. 1, p. 212, Jan. 1942.
7. Fage, A. and Townend, H. C. H., "An Examination of Turbulent Flow with an Ultra-Microscope", *Proc. Royal Soc. Ser. A*, Vol. 135, pp. 656-677, London 1932.
8. Goldstein, S., *Modern Developments in Fluid Dynamics*, Oxford Univ. Press, 1938, p. 293.